

Intake Dam Fish Passage Study

Jeffrey T. McClenathan, P.E. ¹

¹ Chief, Hydraulics Section, Hydrologic Engineering Branch, Omaha District, U.S. Army Corps of Engineers (CENWO-ED-HD), 106 South 15th Street, Omaha, NE, 68102, 402-221-4578, jeff.t.mcclenathan@usace.army.mil

Abstract

In June 2002 the U.S. Army Corps of Engineers, Omaha District, completed a fish passage alternatives study for the Intake Dam on the Lower Yellowstone River. The study was to provide passage for the endangered pallid sturgeon around a low head rock dam used for irrigation. In coordination with the U.S. Fish and Wildlife Service, the Bureau of Reclamation, and the Montana State Game and Parks, the study concluded that more data on swimming capabilities were needed to adequately design a fish passage structure. Together the group agreed to do laboratory studies using shovelnose sturgeon as a surrogate species. Swimming capability studies were conducted at the Bureau of Reclamation's hydraulic laboratory in Denver, Colorado using shovelnose sturgeon captured from the Yellowstone River. The results indicated that shovelnose sturgeon had better swimming capabilities than previously realized. A concurrent study funded by other sources indicated that pallid sturgeon swimming capabilities exceeded those of the shovelnose sturgeon. With this information, fish passage alternatives were evaluated and provided to the Bureau of Reclamation for their implementation.

Background

The Intake Dam study area is located along the Yellowstone River in southeastern Montana approximately 17 miles downstream from Glendive, Montana and about 72 miles upstream from its confluence with the Missouri River. (See Figure 1). The Intake Dam is part of the Lower Yellowstone Irrigation Project. The Lower Yellowstone Irrigation Project was constructed by the Bureau of Reclamation (Bureau) between 1905 and 1909 to provide irrigation for northeastern Montana and western North Dakota. The diversion dam is a low-head structure constructed of timber and rock. The dam is subject to extreme wear at times due to the tremendous ice load in the river that can occur in the spring. A fish passage structure constructed at Intake Dam would modify the federal project, which is owned by the Bureau of Reclamation and operated by the Lower Yellowstone Irrigation District.

The Biological Assessment on the Operation of the Yellowstone Diversion Dam concluded that the dam, in its current configuration, is blocking the upstream migration of pallid sturgeon (Bureau of Reclamation, 2001). By providing fish passage through Intake Dam, the Bureau and the Lower Yellowstone Irrigation District could assist in the recovery of the pallid sturgeon.

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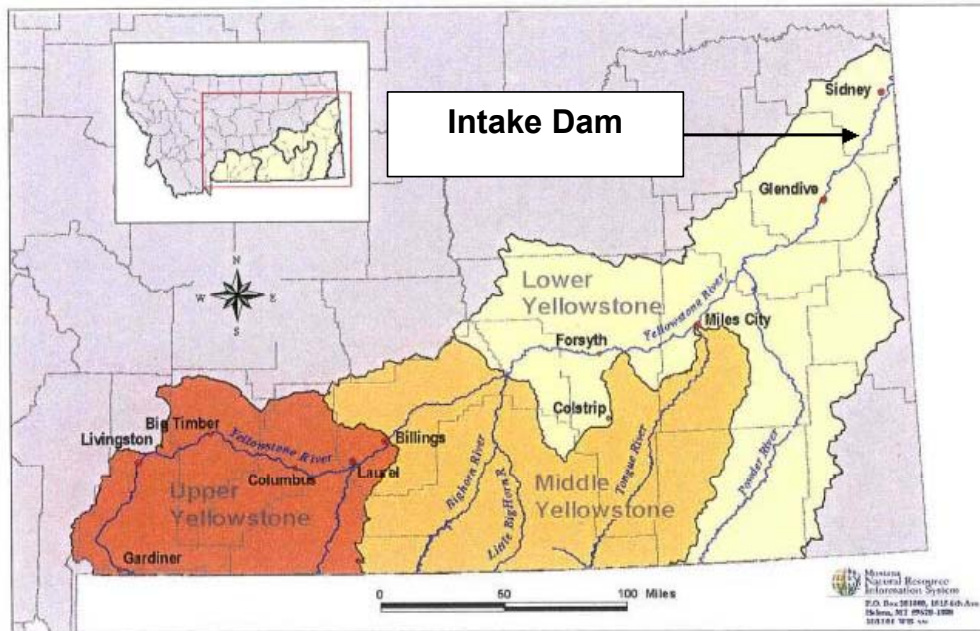


Figure 1 Project Location

The purpose of the study is to assist the Bureau of Reclamation in exploring alternatives for fish passage at the Intake Dam by facilitating discussion among the agencies and the Lower Yellowstone Irrigation District, and to recommend a plan that would meet the needs of the irrigation district and the environmental agencies to provide fish passage at the Intake Dam. It is anticipated that the Bureau will develop the detailed design for construction with future appropriations.

Project Data and Operational Constraints

The existing dam extends about 700 feet across the Yellowstone River. Intake Dam rises approximately 8 to 10 feet above the channel bed. The crest of the dam varies from elevation 1989 feet (N.G.V.D) at the left (north) channel bank (looking downstream) to elevation 1987 feet at the right (south) channel bank. The dam extends about 135 feet longitudinally along the channel and consists of a 1 vertical on 2 horizontal (1:2) upstream slope, a 15-foot wide crest, and a 100-foot long 1:10 downstream slope.

In reviewing the information provided, there appears to be one primary operational constraint to consider with regard to the design of the fish passage structure: meeting the target irrigation diversion discharge. The purpose of Intake Dam is to divert water into a canal for irrigation purposes. In order for the canal to have sufficient water during the irrigation season, a minimum river elevation difference ("head") is needed to divert the 1400 cfs allotted for the intake canal. The fish passage structure

should be designed to operate while ensuring that enough head remains to meet the purpose of the intake structure.

Pallid Sturgeon Overview

Like many other species, the decline of pallid sturgeon (*Scaphirhynchus albus*) populations can be attributed to massive habitat alterations (Bramblett, 1996). Dams, such as those found on the Yellowstone and Missouri Rivers, create barriers for pallid sturgeon migrating into spawning environments. Pallids move out of the Missouri River and up the Yellowstone River as the photoperiod and discharge of the Yellowstone is increasing (Bramblett, 1996). During this time of high discharge, the pallids spawn in the Yellowstone River where they reside until photoperiod and discharge decrease in late summer (Bramblett, 1996). They then move back into the Missouri River.

Pallid sturgeons are non-guarders (they don't actively guard their eggs) and are open water/substratum egg scatterers with an adhesive egg. The eggs must be scattered over an adequate substrate that would allow the egg to adhere to and stay in the appropriate habitat. After 3-8 days, the eggs hatch and the sack fry are carried downstream by the current until they reach suitable rearing habitat. The further upstream the pallids spawn, the longer the larval fish will have to drift downstream before reaching impounded waters without riverine conditions. This gives them more time to develop and select the appropriate habitat necessary for their survival (Krentz, 1999). The ability of pallid sturgeon to move far upstream is considered critical for the survival of their species (Bureau of Reclamation, 2001).

Pallids have historically been found in large, turbid riverine habitat with a firm sandy or gravelly substrate (Bramblett, 1996). Pallids are typically found in areas with velocity breaks from linear flows such as downstream island tips or on or near the bottom of the channel. These areas allow the pallids to use their body morphology to its full advantage (Bureau of Reclamation, 2001). Pallids are not adapted to navigate turbulent waters and are not very strong swimmers (Bramblett, 1996). Over the years, the displacement of rocks by ice and the periodic addition of new riprap have created a rocky river bed that extends downstream from the dam. This rocky substrate, along with turbulent flows, make passage at the dam difficult for these sturgeon.

Pallid Sturgeon Considerations

Sturgeon in North America consist of two primary groups; the *Acipenser* genus and the *Scaphirhynchus* genus. The pallid and shovelnose sturgeon are river sturgeon of the *Scaphirhynchus* genus. All sturgeon have the same basic shape and physical structure; a flattened body with barbels and bony scutes. Sturgeon have been documented as passing through fishways, although most fishways to date have not been designed specifically for sturgeon.

To the best of our knowledge, there are no fishways currently operating that have been designed specifically for sturgeon (any species), although at least one structure for the lake sturgeon is in development. There are no structures designed, or in progress, specifically for *Scaphirhynchus* species. The design of a fish passage structure for the pallid sturgeon, a rare species for which little specific life history information is known, will likely need to rely somewhat on swimming capability and behavior information from the closely-related shovelnose sturgeon, other sturgeon species, and other warm-water fishes.

Since pallid sturgeon are not strong swimmers (Adams et al, 1999), they remain close to the channel bottom, and do not jump over obstacles, therefore only a few fish passage designs can be considered for their use. Benthic (bottom-dwelling fish) such as pallid sturgeon could use certain baffle-type passages. The weir and orifice design facilitates the upstream movement of fish that prefer to move along the bottom, rather than leaping over obstacles (USACE, 1996). Some wild shovelnose sturgeon were able to navigate vertical slot and dual slot fishways, although the fish appeared disoriented and passage success was poor (White and Mefford, 2002).

Three primary questions with regard to sturgeon capabilities came up repeatedly at meetings with the U.S. Fish and Wildlife Service and the Montana State Game, Fish, and Parks Department. These questions were:

- **Attraction to structure.** Would the location of a structure entrance (fishway, rock ramp, or elevator) at a large scour hole be an attracting feature encouraging upstream fish movement through the structure? Would attractant flows or guidance assist in pallid sturgeon use and the success of the structure in passing pallid sturgeon?
- **Laminar versus turbulent flows.** Do pallid sturgeon tolerate turbulent flows such as those within a baffled fish passage system? What laminar flow velocities can pallid sturgeon tolerate?
- **Navigational capabilities.** Could pallid sturgeon find a structure entrance (fish pass, rock ramp, or elevator opening) that is only a fraction of the length of the dam? Could pallid sturgeon navigate through a baffled passage?

It was these unanswered questions that prompted the development of the scope of work that was ultimately awarded to the Bureau of Reclamation - Water Resources Research Laboratory (White and Mefford 2002). The group decided that shovelnose sturgeon could be used as a surrogate species for the pallid sturgeon for the study.

The results of the White and Mefford study, and a parallel study by Kynard et al with regard to the three primary questions above are described in the following sections.

Attraction to Structure

Velocities between 2 and 4 feet per second were recommended for fishway attraction velocities. In velocities of less than 4 fps, sturgeon were able to actively swim for more than ten minutes. This velocity range would be a useful criteria to use for fishway options requiring sustained swimming (White and Mefford 2002).

Surprisingly, sturgeon were able to hold a position with little apparent effort ("facing" velocity) in flow velocities as high as 7.8 ft/sec. Many of the sturgeon (47%) were able to successfully negotiate a channel with velocities as high as 6 ft/sec. Although sturgeon could successfully move through high velocities, they were not able to "hold" for very long, and would not be expected to maintain their position at high velocities for extended periods. This supports the theory that a shorter fishway length would be advantageous.

In a separate study, Kynard et al (2002) indicated that average swim speed for sturgeon (pallid and shovelnose) in laminar flows within a circular test flume were 1 body length per second. In turbulent flows, pallid sturgeon had slightly higher swim speeds (0.9 - 2.0 body lengths / second) than shovelnose sturgeon (0.6 - 0.9). Sturgeon in all tests in laminar flows corresponding from zero to 67 cm/sec (2.2 ft/sec) velocities utilized sustained swim speeds.

Laminar vs. Turbulent

Turbulent flows, as suspected, did pose a hazard for upstream navigation. White and Mefford tested both horizontal turbulence and vertical turbulence. Although both types of turbulence ("eddies") could be negotiated, larger eddies tended to cause delays in upstream movement. As eddy size increased, passage success decreased. Eddy size is a function of baffle size and velocity. Even high baffles (22.5 inch) could be navigated successfully at low velocities (1.6 ft/sec). Since baffle size and placement function to slow the current to within acceptable velocities for the targeted fish, care must be taken to avoid development of large eddies if the passage structure is to function successfully.

Navigational Capabilities

The wild Yellowstone shovelnose sturgeon showed a surprising ability to navigate vertical slot fishways and rock ramp fishways during the White and Mefford tests. However, as eddy size increased (representing turbulence), success in passage decreased. This pattern was seen in the standard vertical slot and the dual slot prototype fishways. Flow velocities of at least 2 ft/sec were needed to properly orient the fish for passage through the structure. Even during fall testing (post-October, 2001) when fish appeared to be less motivated to move, some shovelnose sturgeon successfully maneuvered all three fishways tested (two baffled fishways and the rock fishway).

The White and Mefford study reinforced concerns about turbulence and the avoidance of large eddy development in the design of structures to be navigated. In addition, this study tested fishway navigation capabilities for three types of fishways:

a standard vertical slot fishway, a duel slot fishway, and a rock ramp fishway. These tests were performed during the fall when the fish may have had motivational problems, however they still provide some useful information. Only about 25% of the fish passed all slots, and that occurred when slot velocities ranged from 3 to almost 4 ft/ sec. However, 62.5% of the fish passed through the rock fishway, also during fall testing, so of the three structures tested, the rock fishway was the most successful.

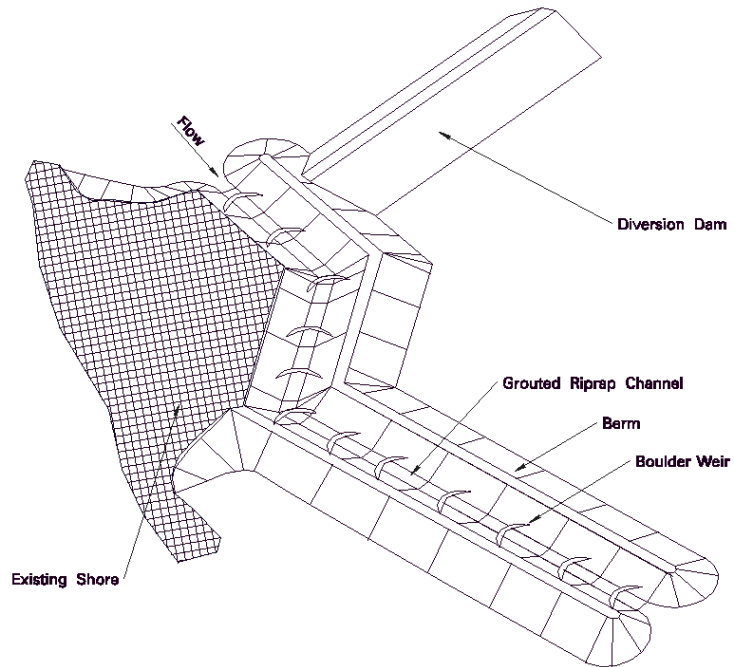
In the 2002 study by Kynard et al, hatchery-raised pallid and shovelnose sturgeon were tested in a circular half-meter wide flume with a 6% slope. Flow was provided using a water pump. Upstream progress was monitored visually and using information from transmitters attached to each fish and receivers placed along the flume. One section of the circular flume contained baffles, which were negotiated by both the pallid and shovelnose sturgeon, however the rate of travel was greater for pallids than for shovelnose. Both species of fish avoided baffle-formed eddies and continued swimming within the main current

Alternatives

Seven alternatives were investigated for this study:

- Grouted Riprap Fish Ladder (wall and berm options; depression and boulder options)
- Riprap Fish Ladder with Boulder Weirs
- Bypass Channel to the South of Intake Dam
- Baffle Fish Passage
- Fish Elevator
- Infiltration Gallery\Pumping
- Collapsible Gates

Of the seven alternatives being considered to provide fish passage at Intake Dam, only five were modeled in the hydraulic analysis. The fish elevator and infiltration gallery were not modeled. The fish elevator uses a locking system that would not be suitable for a steady state model. The infiltration gallery would remove the dam and was not hydraulically modeled. For brevity, only the riprap fish ladder with boulder weirs is shown here. Figure 2 shows an typical isometric and Figure 3 shows a typical plan view prepared for study alternatives.



**GROUTED RIPRAP FISH LADDER PASSAGE
WITH RIPRAP BERM AND BOULDER WEIRS**

Figure 2 Isometric View of Grouted Riprap Fish Ladder with Boulder Weirs

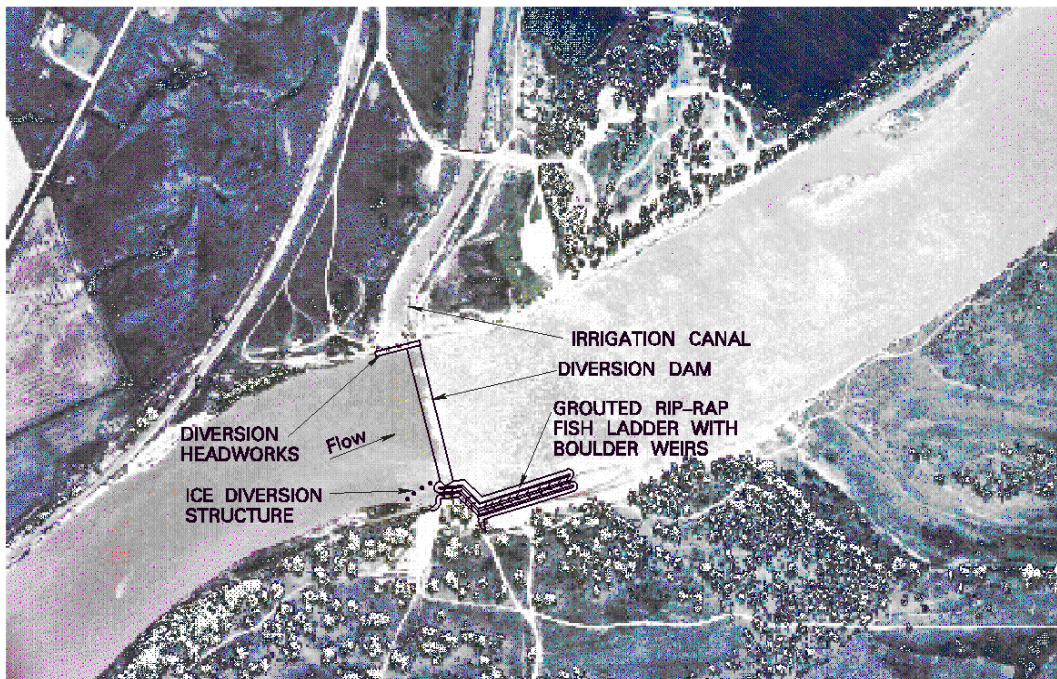


Figure 3 Plan View of Grouted Riprap Fish Ladder with Boulder Weirs

Hydraulic Modeling

The HEC-RAS model used in the Bureau report entitled: *Intake Diversion Dam, Yellowstone River, Fish Protection and Passage Concept Study Report*, dated January 2000 was used as the base model for this analysis effort. This report describes the details of the model, which will only be summarized here. The survey data was obtained in April of 1999. The model was calibrated to the water surface elevations measured at the time of the survey. All modifications made to the model were done to reflect changes in flow conditions as a result of the alternative being studied.

Four discharges were modeled for the Yellowstone River. These are shown in Table 1 with the target flows for the diversion channel. It was quickly noted while running existing conditions (before any fish alternatives were added), that the target diversion flow of 1400 cfs could not be accomplished for a Yellowstone River flow of 5000 cfs. The target was then reduced to 1170 cfs as computed by the HEC-RAS model. The flows used for the Yellowstone River, as shown in Table 1, were those used in the January 2000 Bureau of Reclamation report for consistency. The flows also represent the wide range of flow conditions possible in the study area.

Table 1 HEC-RAS Model Flows and Intake Gate Openings

Computed Canal Discharge for Existing Conditions				
Yellowstone River Discharge In cfs	Target Canal Discharge In cfs	Gate Openings for existing conditions	Computed Canal Discharge In cfs	Exceedance Frequency for May to July Time Period
5000	1400	11 open 5 feet	1170*	97%
15,000	1400	11 open 3.3 feet	1410	70%
29,500	1400	11 open 1.7 feet	1400	35%
38,800	1400	11 open 1.6 feet	1400	22%

* This was the maximum discharge computed to be diverted to the irrigation canal for existing conditions and was below the target discharge. The 1170 cfs discharge will be the target for all alternatives.

As such, the purpose of the one-dimensional HEC-RAS model was to calculate average velocities and the distribution of flows for comparison purposes in the alternative evaluation. Therefore, there is more confidence in the calculated distribution of discharges than in the calculated average velocities. The models cannot identify spot velocities or vertical or horizontal turbulence. It is recommended that physical model studies be used if such data is required, since they provide the most accurate and meaningful data.

For the HEC-RAS model, average roughness values for the structures were used to help model the wide range in discharges. Channel roughness actually depends on the size of the rock in the channel and the flow depth. Given the range of flows being considered there will be a large variation in the channel roughness, especially at lower flows (higher roughness values). Therefore, the roughness values were selected to err with calculating higher velocities at lower river flows.

The modeling of alternatives showed all alternatives could support existing conditions water diversions except for the collapsible gate alternative. For a discharge of 15,000 cfs, the collapsible gate alternative would decrease diversions discharges when five or more gates were lowered.

Conclusions

At this time none of the alternatives should be eliminated since each has its advantages and disadvantages based on the preliminary analysis.

Based on the information used for this document, the alternatives with the greatest potential for pallid sturgeon passage are the dam removal options (infiltration gallery alternative and collapsible gate alternative) and the riprap fish passage options with boulders. Fish passage alternatives with high flows were undesirable, but some alternatives had resting areas that addressed this concern. The extremely high construction cost of dam removal options essentially remove those options as viable, from a funding standpoint. After consideration of cost and other factors, the nature-like (especially rock ramp alternatives) are recommended.

While the ranking reflects the information from the boulder weir design used by the Bureau of Reclamation in the sturgeon swim study (White and Mefford 2002), and the Corps, it should be noted that there are other boulder weir designs that should also be considered. Due to time and funding constraints, these designs were not included as part of this alternatives analysis.

Subsequent to this study, the Bureau of Reclamation has completed a value engineering study. Based on the results from the value engineering study, the Bureau of Reclamation is pursuing construction of a grouted riprap fish passage with boulder weirs and possibly the reconstruction of at least part the almost 100-year-old dam with collapsible gates.

Acknowledgements

The Bureau of Reclamation provided staff for meetings and document review, as well as assisted in funding the shovelnose sturgeon swim study. The U.S. Fish and Wildlife Service, Lower Yellowstone Irrigation Project, and the Montana Game, Fish and Parks also provided staff for meetings and document review.

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